Design, Development and Implemementation of a Steering Controller Box for an Automatic Agricultural Tractor Guidance system, Using Fuzzy Logic

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Abstract- **This study describes the development of a box for controlling the direction of an agricultural tractor, which means the movement of the steering wheel will get the desired orientation, along with its design and implementation. The final task of the box will be part of an autonomous guidance system. There will be an explanation for both software and hardware level. In addition, a brief will explain the control method used in the application: fuzzy logic. Finally, we present the experimental results obtained with step-type entries with different amplitudes, with particular emphasis on test signals similar to those obtained in the self-guided tractor that most of the time is in a straight line. Final results were satisfactory to obtain the response of the controller that is similar to the reference signal to be pursued, with a maximum delay of 2 seconds to complete the shift of direction, while for small jumps of 1.5 º is achieved the establishment in an average time of about 0.5 seconds.**

I. Introduction

The issue that occupies this study, the control theory, is an interdisciplinary field of mathematics and engineering, where it is and analyzes the behavior of dynamic systems. The objective of control is to alter the behavior of a system to present this particular conduct. At the exit you want to get the system referred to as a reference. Thus, when one or more of the variables of the output needed to keep a certain reference, a controller handle, in the right way, the plant's system to get the effect you want in the output. In [1] provides a comprehensive review of the control theory, reviewing the origins and key domains of application.

There are numerous publications in the field of control theory to illustrate in a more or less didactic, as the case, the particularities of this mode field. The book [2] provides a good reference, as it presents complex treatments of the analysis and design of control systems. In addition, it requires a comprehensive mathematical knowledge for the management of differential equations and calculating matrix mathematics among other disciplines. As far as the drivers using fuzzy logic, there are numerous publications [3], [4] and [5]. Reference [3], is a simple analysis of didactic manner, without going into unnecessary complex mathematical analysis. References [4] and [5] present a theoretical vision of such drivers supplemented with practical examples of control. There are books such as [6] where there are different components for the control systems or [7] which describes the functioning of the observers in that area.

There have been various studies for motor control applications with different techniques. To make the driver, in many cases it is necessary to identify a model for the engine. Regarding the attitude control engine using fuzzy logic are numerous studies of similar applications to which it intends to develop. Work of this kind can be seen at [8], [9], [10] and [11]. In addition, the method of control to be used in this document, there are others that have been studied and developed in various scientific papers, highlighting the classic control and easier PID. Among these, there are items like [12] and [13] where he also studied numerous ways to improve the operation. There are, likewise, many jobs where we compare the results produced by different forms of development of a single driver [14] and [15].

In regard to the implementation of final control developed, precision agriculture, has suffered a major breakthrough in recent years. There has been a revolution in terms of guidance, that has improved the performance [16]. References [17] and [18] review the state's guidance in the regions of Europe and North America respectively. There are many ways of conducting guided by artificial vision [19], using GPS and differential ways to improve the accuracy [20] and [21], using a steering geomagnetic sensor (INS) [22] or through a combination of them [23]. For the direct control of the steering actuators are used, which may consist of an electrohydraulic system [24], or simply by driving a motor connected through a pulley system that rotates in solidarity with him.

In this paper we explain how it has been designed and implemented a controller module from the direction of an

M. Iskander et al. (eds.), *Technological Developments in Education and Automation*,
DOI 10.1007/978-90-481-3656-8_30,

agricultural tractor acting directly on the steering wheel. The design is divided into two distinct parts, one implements the hardware and the other part the software. To complete the study, concrete results will be presented for one of the theories of control implemented in the box. In this way, section II presents the objectives of the study and III is a brief description of the materials and real system to be monitored. In successive paragraphs IV and V will explain the hardware and software, respectively. Finally, VI presents a series of results obtained during testing validation of the box controller and the control method implemented.

II. OBJECTIVES

The aim of this study is to construct a box controller to move the steering wheel and, consequently, the address of an agricultural tractor. Thus, a design for both software and hardware levels is made in order to create a versatile device that can act as a controller with different control algorithms. Regarding to hardware, it is necessary for the system to be robust and reliable.

Once built the controller, an algorithm using fuzzy logic control will be implemented to control the positioning of the direction of the vehicle. The control through fuzzy logic is the relocation of human language to the level of control, namely to build a controller that functions intelligently as you would a person. Thus, it will make the guided according to the angular distance to be travelled to the destination point, using different functions diffuse, with triangular and trapezoidal shapes.

Once the controller box is designed, with the controller tuned properly, the results obtained on the real system will presented. To evaluate the operation a sign of stairs with different amplitudes will be used in order to have a broad knowledge of the response.

III. MATERIAL

For the tests a tractor model KUBOTA 6950DT with 53 KW of power maximum, figure 1, will be used. On this vehicle was implemented a system of steering control. The control system of management is based on a dynamo who serves as the actuator for the steering wheel through a system of pulleys and a sensor in the direction potentiometer.

The actuator system can be seen in the left of the figure 2. The advantage of using a dynamo is that by having a system operating under is not necessary to use any type of gear reducer for the movement of the steering wheel. As the dynamo interface will be used a commercial driver MD03 of the company Devantech Ltd, which provides a maximum of 20 A to the actuator of the steering wheel of the vehicle.

Figure 1: Kubota tractor 6950DT.

The direction sensor, a pot of low cost, stood at the cross of the direction of the tractor. Thus, we get a spin-axis sensor solidarity with the movement of the wheels of the vehicle. In the right of figure 2 may be the position of the pot near the left front wheel of the tractor.

Figure 2: Parts of the system of control over the direction.

For the findings of the functioning of the application in the box controller was used a laptop with an Intel Core 2 Duo 2 GHz, 1 GB DDR2 and 160 GB hard drive. The operating system used was Windows XP and the development environment on which is scheduled implementation of the computer was LabWindows CVI.

IV. HARDWARE DESIGN

For the hardware in the box controller two separate circuits are used. The first is, so to speak, the brain of the system. It is the microcontroller that is responsible for the finality of the system. The power to be used for this part of the circuit, comes from the computer which is responsible for sending the orders to the controller box. The second circuit will be an assistant to isolate the power part that connects the engine to control part connected to the microprocessor, to be funded by the tractor's battery. The voltage from the battery of the tractor may not be uniform given its nature and be connected to a DC motor that can generate spikes harmful to sensitive parts of the circuit. This will seek to avoid possible damage that might occur in the microcontroller or on the computer. In figure 3 may be a general outline of the different parts of the hardware that is the system that will be described in subsequent paragraphs.

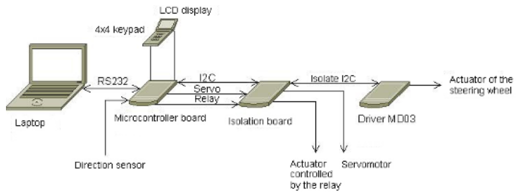

Figure 3: Outline of the system hardware

A. Microcontroller board

This board, as indicated above will be part of the intelligent controller box. It is the fundamental part of the control system: the microcontroller where the algorithm that will be responsible for the leadership position in the angle requested. Microcontroller was chosen as the PIC16F876A of the company Microchip. This device is useful because it has different interfaces for the control of different parts of the system.

The main interfaces of the system will be a 16-character LCD display and two lines and a 4x4 keypad, which will be used to display information on the application and to act directly on the system. It is also necessary to communicate with different devices in the system. For liaison with the computer will use the RS232 interface, while for sending the orders to the stage of engine power will be used to address the I2C protocol. Both interfaces are present in the microcontroller, which will facilitate, to a large extent, the communications to be carried out. For the RS232 interface is a need for a commutation of external levels for the system to work properly. This will be achieved with the help of an integrated circuit business called MAX232, which is capable of converting voltages with an RS232 to TTL Power 0 and 5 V.

In addition to the interfaces of the system, both for communication and information to the user, this board will connect the signal from the sensor to directly address one of the analog inputs of the microcontroller. It will also be necessary to send signals to the sensor power supply so the connection to this will be done through three cables. Will be generated in this part of the circuit control signal for a servomotor and a relay for the control of other tractor components such as the accelerator or the raising of the apero being processed.

As indicated above, the 5 V power necessary for the functioning of the entire plate is obtained from the computer which is responsible for sending the orders of positioning system. This is possible because the total consumption of the entire board is very small.

In figure 4 may be a comprehensive outline of the circuit built in the board of the microcontroller.

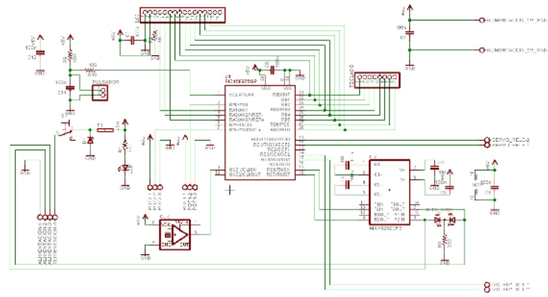

Figure 4: Designed for circuit-board PIC

B. Isolation board

The circuit part for the isolation of signals will be very important because the power system of the actuator is made from the battery of the tractor and is a source is quite irregular. Also, using a DC motor that makes the signal power of the engine from being disrupted, such as voltage spikes, which can be very damaging to sensitive parts of the module controller of the address.

To separate electrical signals are used two different magnetic insulators in the series iCoupler of Analog Devices. It will be necessary to use two different kinds of insulators. The first, it will be a special device for the isolation of signals from the I2C protocol. As a result, it has two channels of bi-directional communications. These signals are those connected with the phase of Microcontroller power. The second isolator is necessary to avoid direct connection between the signals from the microprocessor and different hardware devices in the system fed again with the battery of the tractor such as the relay and the servomotor. This second device, has two unidirectional channels of isolation perfect for the application that aims to develop, where the aim is to isolate two signals separate. One advantage of these insulators is that any external packaging through discrete components is needed, resulting in a high space savings and simplicity in the design.

Insulators require employees to use two power supplies 5 V to achieve these feeds will be used on one side of the block from the computer's microprocessor and on the other hand, the signal from the battery of the tractor stabilized by two stabilizers tension of the series 78XX properly connected through an auxiliary circuit filter.

In Figure 8 6 shows the design circuital used for the plate insulators needed in the controller box.

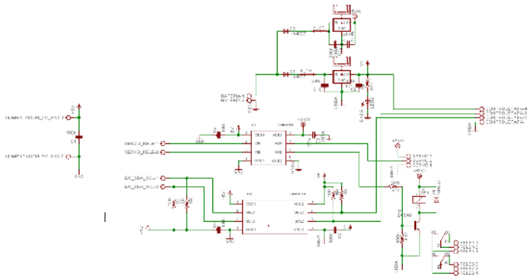

Figure 5: Circuit designed for the insulators board.

C. Power stage

To adapt the signal from the microcontroller and the board of insulation DC motor that moves the steering wheel will be necessary to add a power stage. For this purpose, was chosen the driver of MD03 commercial power of the company Devantech Ltd which will provide some signs of feeding more than sufficient for operating the engine to be monitored. Its configuration is based on a bridge in H and is capable of controlling motors up to 50 V with an intensity of 20 A. In addition, this driver allows different forms of control such as analog signals at the entrance or the one used in this case, through the I2C protocol. In Figure 6 shows the overview of the MD03 module to be used.

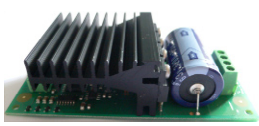

Figure 6: Overview of driver MD03

V. SOFTWARE DESIGN

As far as the software programmed into the microcontroller C was used as a programming language, and the C language compiler for PIC microcontrollers PCWH of the company CCS (Custom Computer Services Incorporated). Different laws will be used to control the movement of the direction, but they all use the same flow diagram which is summarized in figure 7. It may be that after an initialization of variables and the complete configuration of all devices and extras that will be used in the integrated circuit that is responsible for supervising the application, asks the user to perform a manual calibration, consisting of recording the values of the leadership on both sides, and finally in the center, or, conversely, use a calibration pre-stored on the computer. To make the distinction between whether or not it has been calibrated, the computer will analyze the message received. When it is empty, it will respond with the correct calibration message. By contrary, the computer saves the new calibration data. After the calibration of the system, the microcontroller will await the rest frame of driver settings from the computer, you'll need different kinds of parameters depending on the type of controller implemented.

When everything is configured correctly is time to come into the loop controller. The value driver will be updated with a sampling period of 10 ms by a temporary interruption. The first step of the process is to read the position, in that instant, sensing direction. Once this is done it will update the value on the LCD screen informing the user and also, if the option is active sampling external and has defeated the corresponding timer, 50 ms, a message will be sent to the computer with information from the position for the subsequent processing of the dynamics of the system. After shipments of information by various interfaces, is the calculation of the corresponding control algorithm for the configuration data that have been sent. Once the calculation is processed properly and, finally, it sends the information to the phase of power that will attack the DC motor. At this point ending the cycle of the program until the next break, at which it begins, again, the whole process of control.

First, it will receive and store the message completely, after completion of the receipt, checking the header and type of message. If both are correct, it will process data containing the message and all the variables will be updated as necessary. When you're done correctly, or the receipt, whether on the contrary, errors were detected in the header or the type of message is left of the interruption of receipt of fabric.

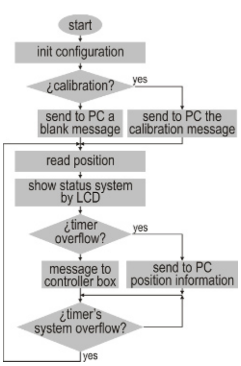

Figure 7: General organizational chart of the applications developed

To establish communication with the computer and, as might be assumed by reading the preceding paragraphs, has designed a communications system based on messages of two lengths. The different lengths are for fixed two-way communication microcontroller-computer and vice versa.

As a security measure a control of connectivity with the computer is enabled; by default, it will not be activated.

To get a complete and optimal functioning of the system were designed frames to modify all the parameters relating to the control method and the different options that allows the program.

D. Control Law implemented: fuzzy logic

For the control method that is developed will be implemented three and two triangular-shaped trapezoid, as shown in figure 8. The system of duties will focus vague on the point you want to reach and, thus, will be approaching it with a gain increasingly marginalized.

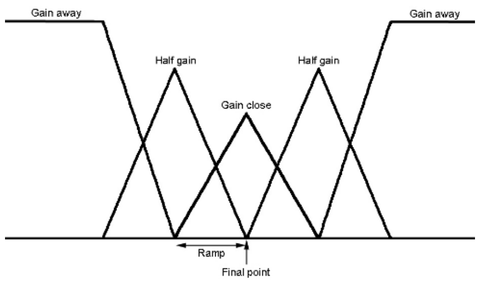

Figure 8: Functions of fuzzy logic.

For the application of control, firstly, we need to know the region of figure 8 this positioning sensor, once it knows this, apply the equation (1), where PA denotes the point where the system at that instant, O1 and O2 are the origins of the respective lines, gain1 and gain2 are the heights of each of the two lines, and finally ramp is the value of the width, as shown in figure 8, if the item is in a region with two ramps or (2) if it is on the step.

$$u(t) = \pm\left(\left(PA - O_1\right)\frac{Gain_1}{Ramp} + \left(PA - O_2\right)\frac{Gain_2}{Ramp} \right) \tag{1}$$

$$u(t) = \pm(Gain\ \ away) \tag{2}$$

The controller tuning is done on an experimental basis in the real system to monitor the management response to changes made in the final set of turn. The final values of the parameters used in the controller, the gains for all functions and value of the width of the ramp, are presented in (3). The value for the ramp angle is measured in the direction, that is, denotes the distance to the end point from which to begin to act that role.

$$\begin{aligned} Gain\ \ close &= 130 \\ Half\ \ gain &= 160 \\ Gain\ \ away &= 243 \\ Ramp &= 17.5^{\circ} \end{aligned} \tag{3}$$

VI. RESULTS

Once constructed the box for controlling the system of management were conducted numerous tests, based mainly in response to different step for changes in the angle of the wheels, to know the performance of each of the theories of control with implemented. Here are the results obtained in the case of fuzzy logic which yielded the best performance of the system. The tests were conducted for changes in the slogan of position of entry. In figure 9 the data obtained is presented graphically. The horizontal axis represents time in seconds and the vertical axis positioning units in the angle of the front of the address farming tractor to be monitored.

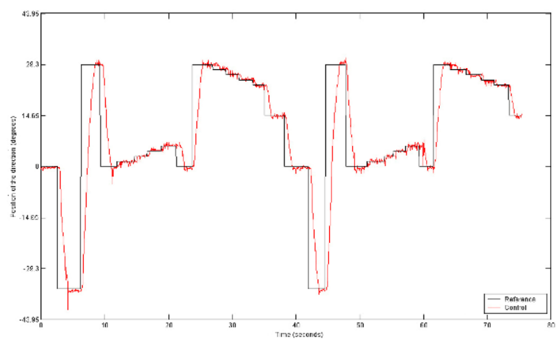

Figure 9: Results obtained for the control through fuzzy logic..

As shown in figure 9 alternated big jumps in the position of the leadership of approximately 29 degrees, with small intervals (1.46 degrees) as it would be an application of self-guided. In figure 9 can be seen that the driver still follows pretty well all the position changes that have been made, that are even smaller. The response time is slightly less than 0.5 seconds, for the worst case measured, since the microcontroller receives the new position until it begins to rotate the leadership to get to it. In addition, there is no excess, while the time needed to make a turn almost entirely on location is, from reaching the new position, slightly more than 2 seconds until the stabilization in the position of destination, although such changes are not used in applications normal guidance. Delays for small changes in the direction of the wheels of 1.5º are approximately 500 ms. Changes to intermediate values of stabilization are around 1 second as shown in figure 9. That the oscillations were observed in the area where the system is stabilized are due mainly to the quality of the sensor and in any case not exceed the value of 1º, therefore poses no obstacle for the application that aims to develop.

VII. Conclusions

In carrying out the experimental evidence has been necessary to implement a system of guided self on a real tractor. This study summed up the task of building a box for controlling this system of guided tractor.

The hardware consists of three distinct parts, on the one hand, the stage of the microprocessor fed with the signal from the computer, a second part of electrical insulators to be responsible for isolating the signals that are at the computer with the voltage coming from the battery of the tractor. Finally, phase three will be responsible for directly attacking the engine management, is the amp by the commercial driver MD03.

Regarding the software various control techniques have been implemented getting satisfactory answers in the positioning of the wheels, making the measures of this position through a sensor on the front axle of the vehicle.

The program's structure consists of a boot, a calibrated and finally the direct application of the algorithm used to control. In addition, it has enabled a system for sending and receiving frames, via post series, to achieve the fullest possible communication with the computer. With these messages all the factors of the driver will be monitored. It has also implemented a system for monitoring the physical connection to the computer in case of detecting loss and generates an emergency stop the driver.

The program that will control assistant in the computer has been developed in the LabWindows CVI, a development tool based on a similar LabView, but applying programming in C language for control. It is allowed to use a rapid development from numerous libraries and graphical environments implemented.

As evidence of performance appraisal system is a sequence of job positions that reflect the behavior of the system in a comprehensive manner, making big changes in the angle of the steering and small jumps of about 1.5 º to give idea of the behavior of applications in guided actual conventional farming. Values are obtained for the establishment of 2 seconds to complete turns of direction, but such changes are rarely carried out in guided applications. With regard to small changes in direction, of 1.5 degrees, are obtained delays of 500 ms, while for intermediate values, around 15 degrees, the values were established around a second. The results show that the behavior of the system is perfectly correct and may be used in applications where self-guided changes in the direction of the tractor will be very small as it has been studied in tests done with the real system.

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